Evaluation of military trauma system practices related to complications after injury

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BACKGROUND: The Joint Theater Trauma System (JTTS) was developed with the vision that every soldier, marine, sailor, and airman injured on the battlefield would have the optimal chance for survival and maximum potential for functional recovery. In this analysis, we hypothesized that injury and complication after injury surveillance information diffusion through the JTTS, via the dissemination of clinical practice guidelines and process improvements, would be associated with improved combat casualty clinical outcomes.

METHODS: The current analysis was designed to profile different aspects of trauma system performance improvement, including monitoring of frequent posttraumatic complications, the assessment of an emerging complication trend, and measurement of the impact of the system interventions to identify potential practices for future performance improvement. Data captured from the Joint Theater Trauma Registry on patients admitted to military medical treatment facilities as a result of wounds incurred in Iraq and Afghanistan from 2003 to 2010 were retrospectively analyzed to determine the potential impact of complication surveillance and process improvement initiatives on clinical practice.

RESULTS: Developed metrics demonstrated that the surveillance capacity and evidence-based quality improvement initiatives disseminated through the JTTS were associated with improved identification and mitigation of complications following battlefield injury.

CONCLUSION: The Joint Trauma System enables evidence-based practice across the continuum of military trauma care. Concurrent data collection and performance improvement activities at the local and system level facilitate timely clinical intervention on identified trauma complications and the subsequent measurement of the effectiveness of those interventions. (*J Trauma Acute Care Surg*. 2012;73: S465 S471. Copyright © 2012 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Epidemiologic study, level III.

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The US military's Joint Theater Trauma System (JTTS) was established in 2004 to enable data-driven performance improvement (PI) across the continuum of trauma care within the military health system.[1] This continuum begins at the point of injury and includes evacuation and treatment through all the levels of care, concluding with definitive treatment in the United States.[2] Reduction of mortality and morbidity in military trauma patients is the primary goal of all PI activities throughout the continuum of care. PI happens locally at each military medical treatment facility along the chain of evacuation but is also coordinated and monitored at a system level. One example of system-wide PI is the 37 JTTS clinical practice guidelines (CPGs) created to provide the most current, evidence-based practices specific to combat trauma care. In 2011, the Joint Trauma System (JTS) became the trauma system for the entire Department of Defense in addition to the active theater of war.

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Complications related to combat trauma injuries continue to remain a focal point in the effort to prevent or reduce morbidity and mortality after injury. The Joint Theater Trauma Registry (JTTR) currently tracks 83 complications from time of injury through either death or discharge of the patient from definitive care at a military medical center in the United States. The JTTS has been able to demonstrate reductions in a variety of complications during the conflicts in Afghanistan and Iraq, including hypothermia, extremity compartment syndrome, hemorrhage, abdominal compartment syndrome, and ventilator-associated pneumonia (VAP).[3–5]

This current analysis illustrates three key examples of trauma system PI initiatives related to complications, including identification, surveillance, and PI activities associated with VAP, extremity compartment syndrome, and venous thromboembolism (VTE) in amputation patients. These three clinical complication entities were highlighted in this analysis to profile unique aspects of the trauma system PI process, including monitoring of frequent posttraumatic complications, the assessment of an emerging complication trends, and measurement of the impact of the system interventions to identify potential practices for future PI.

PATIENTS AND METHODS

The US military's JTTR was queried for select demographics and data elements related to mechanical ventilation.

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The patient population included all US military trauma patients admitted to hospital-level treatment facilities in Afghanistan or Iraq, who had mechanical ventilation initiated in theater before evacuation. The period queried was January 1, 2003, to December 31, 2011.

Patients with VAP were identified in the JTTR by either a documented complication of VAP or by the DRG International Classification of Diseases—9th Rev. (ICD-9) code 997.31. The complication definition for VAP in the JTTR complies with the Centers for Disease Control definition.[6] A rate of VAP per 1,000 ventilator days was calculated for each year of the analysis. The mean combined Injury Severity Score (ISS) for the ventilated population was overlaid on the chart to display changes in the patient population severity during the period. Killed-in-action and died-of-wounds patients were excluded from the analysis.

A retrospective PI cohort study was designed to evaluate compartment syndrome and fasciotomy trends in patients with extremity injuries. The JTTR was used to identify US military patients with upper- or lower-extremity injuries admitted to US Level III or North Atlantic Treaty Organization Role 3 military treatment facilities in Iraq and Afghanistan between January 1, 2003, and December 31, 2011. Extremity injury was defined as an injury coded in the Abbreviated Injury Scale (AIS) body region of 7 (upper extremity) or 8 (lower extremity). Compartment syndrome patients were identified in the registry by either a documented complication of extremity compartment syndrome or by the ICD-9 codes 958.91 or 958.92. Likewise, patients receiving fasciotomies were identified using the ICD-9 code of 83.14.

Incidence rates for both compartment syndrome and fasciotomy were calculated for each calendar year in the evaluation period. The rate of compartment syndrome was the number of patients with the complication of compartment syndrome divided by the total number of patients with extremity injuries, the population at risk for compartment syndrome. Similarly, the fasciotomy rate was the number of coded fasciotomies divided by the same denominator.

The focused PI review queried the JTTR for a variety of demographic and clinical elements potentially related to VTE, including vital signs, procedures, injuries, blood products, and medications. The initial query was January 1 to December 31, 2010, but the period of review was later expanded from January 1, 2010, to August 31, 2011. The patient population was limited to only US military patients who underwent lower-extremity amputation from Operation Enduring Freedom in Afghanistan with AIS codes of 811001.x, 811002.x, or 811003.x. VTE events were identified from the JTTR as either deep vein thrombosis (DVT) or pulmonary embolism (PE). Any patient who did not survive past the first hospital level of care was excluded from the analysis as they were considered to have had insufficient time to develop the complications of interest.

The final VTE variables selected from the JTTR query for analysis were initial temperature, massive transfusion (MT), prehospital tourniquet use, sequential compression device use in theater, use of fasciotomy, pelvic fracture or perineal injury, and blood vessel shunt, graft, or repair. Temperature used in the analysis was the first recorded temperature at any level of care in the chain of evacuation. MT was defined as 10 or more units of packed red blood cells and/or fresh whole blood within the first 24 hours following injury.

Chart review was necessary on the identified patients for VTE variables not routinely collected in the JTTR. The US military's Theater Medical Data Store was used to review scans of all patient records. In theater, medication use was reviewed for heparin or enoxaparin (Lovenox), factor VIIa, and tranexamic acid (TXA). Dose and timing were not considered in this analysis, only if the medications were given before evacuation out of the theater. Other variables included in the chart review were head injury, central line placement in theater, and abdominal artery ligation.

All data was evaluated using SAS 9.2 (Cary, NC). Categorical data elements were summarized using percentages. χ^2 tests were used to compare combat trauma patients who developed the complication with those who did not when the expected frequencies were greater than 5 per group. If any expected frequency did not meet the 5-per-group criterion, Fisher's exact test was used. All continuous variables were then tested for normality. Those that met the criteria for normality, means, and SDs were used as summary statistics and complication versus no-complication populations were compared using Student's t test and analysis of variance. Non-normally distributed variables were analyzed using the Wilcoxon rank-sum test, and medians with interquartile ranges were used for summary statistics.

RESULTS

A total of 6,312 trauma patients queried met the inclusion criteria for the VAP evaluation study. Of the total study population, 1.7% of patients (n = 107) acquired VAP, whereas 98.3% of patients (n = 6,205) did not. Overall, the VAP cohort was more severely injured (ISS 2005, 30.2 [15.4] vs. 14.4 [11.6]; $\rho < 0.001$) and remained on a ventilator longer (19.4 [18.4] days vs. 3.4 [10.7] days; $\rho < 0.001$) compared with the group that did not acquire VAP. The unadjusted mortality rate was just more than 6% (n = 398) for the entire study population; however, when stratified by VAP cohorts, there was no statistical difference in the unadjusted mortality rates (Table 1).

TABLE 1. Summary Characteristics for VAP Evaluation Study

	Total Population (N = 6,312)		
Population Characteristic	**No VAP (n = 6205)**	**VAP (n = 107)**	***p***
Ventilator days, mean (SD)	3.4 (10.7)	19.4 (18.4)	<0.001
Combined ISS, mean (SD)	14.4 (11.6)	30.2 (15.4)	<0.001
Deaths, n (%)	394 (6.4)	4 (3.7)	0.268
Theater of operation, n (%)			
Enduring Freedom	1,374 (97.2)	40 (2.8)	<0.001
New Dawn/Iraqi Freedom	4,831 (98.6)	67 (1.4)	
Military service, n (%)			
Air Force	89 (98.9)	1 (1.1)	
Army	4,540 (97.9)	96 (2.1)	
Marines	1,409 (99.3)	10 (0.7)	
Navy	167 (100)	0 (0)	

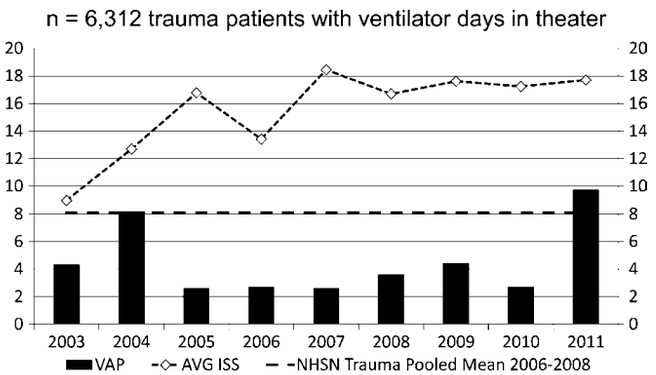

Figure 1. VAP per 1,000 ventilator days.

Although the overwhelming majority (77.6% of the 6312) of patients examined was injured in Iraq (including both Operation Iraqi Freedom and Operation New Dawn), when stratified by VAP cohort, more confirmed cases were diagnosed in patients injured in Afghanistan (Operation Enduring Freedom, 2.8% vs. Operation Iraqi Freedom, 1.4%; $\rho < 0.001$). Table 1 also provides a detailed breakdown by branch of military service. US Army soldiers (73.4%) and US Marines (22.5%) was composed of a significant proportion of patients evaluated with the remainder being US Navy and US Air Force personnel. Approximately 4.7% of cases were diagnosed in theater (US Military Level III/North Atlantic Treaty Organization Role 3), 7.5% in Germany (US Military Level IV), and 87.8% in tertiary medical centers in the United States (US Military Level V).

The yearly incidence rate of VAP per 1,000 ventilator days is depicted in Figure 1. The National Health Safety Network (NHSN) pooled mean for US civilian trauma units from 2006 to 2008, the mid-years of the analysis, provides a civilian comparison. The mean annual combined 2005 ISS for the patient population shows changes in injury severity over time. At the beginning of 2004, the annual VAP rate was 8.2 per 1,000 ventilation days, at par with the NHSN benchmark. This same year, the JTTR also recorded the highest number of all hospital trauma admissions of any year during the last decade of combat operations in Iraq and Afghanistan. Following the establishment of the JTTS in 2004, the rate dropped to 2.6 per 1,000 ventilator days in 2005 and remained less than 5 per 1,000 ventilator days through 2010 despite the steady increase in the mean ISSs during those years. In early 2011, the JTS began to receive reports from facilities of a perceived increase VAP throughout the system. Further investigation seemed to suggest that this anecdotal trend was well founded by a consistent rate of increase throughout the midyear. The final VAP incidence for 2011 was 9.7 per 1,000 ventilator days, the highest recorded rate to date.

Table 2 displays the univariate risk factor analysis for the variables queried from the JTTR. Sedation and paralytics were not included in the analysis since timing and dose are not collected in the registry. Days on ventilator at time of diagnosis were excluded because it is not consistently known in the JTTR how many days the patient was on the ventilator at time of diagnosis, only total ventilator days. All other identified variables, except for the use of nasogastric tubes, were found to be significant risk factors associated with VAP within the study cohort. Furthermore, explosive exposure was also found to be a significant risk factor associated with VAP.

A sample of 17,278 US military patients with extremity injuries was identified from the JTTR. The theater of origin was 5,316 (30.7%) from Afghanistan and 11,962 (69.3%) from Iraq. Patient sample branch of service was Army at 75%, Marine Corps at 21%, Navy at 2%, and Air Force at 2%. During the entire 9-year period evaluated, there were 416 patients with compartment syndrome and 1,412 fasciotomies performed coded in the JTTR.

Yearly incidence of compartment syndrome and fasciotomy per 1,000 extremity injuries is depicted on Figure 2. The years of 2003 to 2005 shows a steadily increasing incidence of compartment syndrome, peaking at 62.5 per 1,000 in 2005. Following the establishment of the JTTS in 2004, the rate of fasciotomy more than doubled to a rate of 116.6 per 1,000 in 2005. From 2006 to 2008, the rate of compartment syndrome dropped from 55.7 in 2006 to 9.8 in 2008, whereas the fasciotomy rate remained greater than 70 per 1,000 for all years. In 2009, the JTTS CPG for compartment syndrome and fasciotomy was published. Since that time, there has been approximately a 40% reduction (from 16.1 to 9.4) in the rate of compartment syndrome and a 40% increase in the rate of fasciotomy use (from 66.5 to 93.5) from 2009 to 2011.

The VTE query from the JTTR resulted in 296 patients who underwent lower-extremity amputation during the 20-month period of the PI review. Of those, 45 (15%) developed a DVT and 39 (13%) developed a PE. Fifteen patients (5%) had both a DVT and a PE. Ten DVT cases (22.2%) were diagnosed in

TABLE 2. Univariate Analysis of Risk Factors and the Occurrence of VAP

Risk Factor	Total Population (N = 6,312), n (%)	No VAP (n = 6,205), n (%)	VAP (n = 107), n (%)	*p*	Odds Ratio	95% Confidence Interval
ISS 16	2,478 (39.3)	2,384 (38.4)	94 (87.9)	0.0001	11.5892	6.4743 20.745
Prehospital intubation	3,369 (53.3)	3,271 (52.7)	98 (91.6)	0.0001	9.767	4.926 19.3656
Head injury	1,835 (29.1)	1,768 (28.5)	67 (62.6)	0.0001	4.2036	2.8305 6.2428
Neck injury	1,488 (23.6)	1,429 (23)	59 (55.1)	0.0001	4.1081	2.7939 6.0406
Thoracic injury	1,611 (25.5)	1,556 (25.1)	53 (49.5)	0.0001	2.9274	1.9953 4.2948
Improvised explosive device	3,149 (49.9)	3,085 (49.7)	64 (59.8)	0.0485	1.5053	1.0195 2.2226
Nasogastric tube	493 (7.8)	479 (7.7)	14 (13.1)	0.0617		

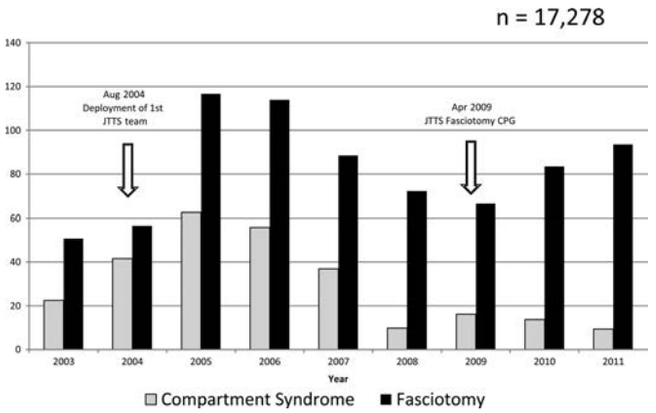

Figure 2. Compartment syndrome and fasciotomy incidence rates.

theater, 30 (66.7%) in Germany, and 5 (11.1%) at military medical centers in the United States. The levels of care that cases of PE were diagnosed were 13 (33.3%) in Afghanistan, 8 (20.5%) at Landstuhl Regional Medical Center, and 18 (45.2%) at military medical centers in the continental United States. Notably, 145 of patients (49%) in the study group had two or more amputations. Furthermore, 19 (13%) of these patients who underwent polyamputation had three or more major amputations. Table 3 shows the results for the 16 variables analyzed for both DVT and PE.

Five variables were significantly associated with development of a DVT in lower-extremity amputation patients, namely, MT, pelvic fracture, placement of a central line, TXA use, and platelet infusion. Of the variables related to resuscitation (MT, TXA, and platelets), only MT independently predicted DVT with a $\rho = 0.023$ and an odds ratio of 3.08. Use of factor VIIa was the only variable found to be significant associated with PE. In addition, DVT was significantly associated with subsequent development of PE with an odds ratio of 4.7 (Table 3).

DISCUSSION

VAP is a common concern in critically injured trauma patients. In 2010, trauma units in the United States had the highest rate of VAP of the 17 types of critical care units tracked by the NHSN.[7] Although pneumonia is the second most common nosocomial infection the United States,[8] VAP is the most common intensive care unit–acquired infection.[9] Several risk factors associated with VAP are tracked through the JTTR, including sedation, length of ventilation, thoracic or cervical trauma, use of paralytics, prehospital intubation, nasogastric tube use, head injury, reintubation, blunt trauma, and injury severity.[10,11]

Trauma care of critically injured patients in the military trauma system presents some unique challenges that distinguish it from civilian trauma care. Combat casualties often experience injuries such as explosion or gunshot wounds that place them at greater risk for infection.[12,13] Military medical personnel operate in austere conditions with atypical equipment, limited staffing, multiple levels in the chain of evacuation, varying hospital capabilities, multinational partners, and host-nation medical limitations.[14,15] Constant staff turnover, both in theater and throughout the military continuum of care, makes it difficult to implement and sustain changes to prevent VAP in military facilities.[16,17] Although it is recommended to minimize out-of–intensive care unit transports to prevent VAP,[18] critical patients are necessarily transported between hospitals through several levels of care in the chain of evacuation, traveling up

TABLE 3. Summary of DVT and PE Risk Factors

Population Characteristic	DVT Analysis Total Population (n = 296)			PE Analysis Total Population (n = 296)		
	No DVT (n = 251)	DVT (n = 45)	*p*	No PE (n = 257)	PE (n = 39)	*p*
Categorical Variables, n (%)						
Application of prehospital tourniquet	193 (76.9)	29 (64.4)	0.076	193 (75.1)	29 (74.4)	0.921
MT	158 (62.9)	39 (86.7)	0.002	166 (64.6)	31 (79.5)	0.066
Hypothermia recorded at initial emergency department	42 (16.7)	10 (22.2)	0.373	41 (16)	11 (28.2)	0.061
Epidural use	55 (21.9)	10 (22.2)	0.963	58 (22.6)	7 (17.9)	0.516
Use of recombinant factor VII	26 (10.4)	9 (20)	0.065	26 (10.1)	9 (23.1)	0.02
Presence of pelvic fracture	41 (16.3)	13 (28.9)	0.045	43 (16.7)	11 (28.2)	0.084
Fasciotomy	60 (24.3)	7 (15.6)	0.218	58 (22.6)	9 (23.1)	0.944
Presence of perineal injury	124 (49.4)	22 (48.9)	0.949	122 (47.5)	24 (61.5)	0.102
Anticoagulant use	198 (78.9)	40 (88.9)	0.119	206 (80.2)	32 (82.1)	0.781
Central line use	192 (76.5)	43 (95.6)	0.004	200 (77.8)	35 (89.7)	0.086
Abdominal artery ligation	27 (10.8)	8 (17.8)	0.179	28 (10.9)	7 (17.9)	0.204
Use of TXA	74 (29.5)	21 (46.7)	0.023	82 (31.9)	13 (33.3)	0.859
Continuous Variables, Mean (SD)						
Whole blood use (first 24 h)	0.62 (2.5)	1.24 (3.7)	0.160	0.73 (2.9)	0.62 (1.7)	0.805
Platelet use (first 24 h)	3.08 (4.3)	4.53 (3.6)	0.032	3.17 (4.2)	4.15 (3.9)	0.174
Cryoprecipitate use (first 24 h)	1.97 (4.2)	2.60 (2.6)	0.33	1.96 (4.0)	2.74 (3.8)	0.255

to 8,000 mi to definitive care at military medical centers in the United States.[19,20] Despite all these challenges across the continuum of care, the expectation is that the care should parallel civilian trauma standards and evidence-based practices, such as VAP bundles, as closely as possible.[21] This goal is reflected in the Ventilator-Associated Pneumonia JTTS CPG first published in November 2007. Adherence to guidelines and implementation of evidence-based practices have been shown to affect the incidence of VAP in both Iraq and Afghanistan.[22–25]

The known VAP rate during the 9-year period is lower than might be expected in the military population considering severity, austere conditions, multiple patient handoffs in the chain of evacuation, and frequent system changes and adaptations. Establishment of a formal trauma system in 2004 contributed to a measurable reduction in the subsequent years. The system distribution of the JTTS VAP CPGs had a less apparent effect, although the CPG reinforced practices already in place in the system and the rate was already quite low in 2007 when it was published. Several other factors may have contributed to the reduction of VAP in the trauma system, including rapid evacuation, establishment of fixed medical facilities in theater, improvements in body and vehicle armor, and increased proficiency of clinicians during multiple deployments.

The recent increase in the rate of VAP in 2011 is concerning. The new Walter Reed National Military Medical Center started registering patients in the JTTR during the last quarter of 2011, accounting for at least two cases (10%) that would not have been reported previously. Proportionally, the number of ventilated traumas resulting from explosive exposures increased in 2011 from 57% in 2010 to 66% in 2011. In addition, the actual cases of VAP associated with explosion as the mechanism of injury were 50% in 2010 and 84% in 2011. Blast overpressure injury, or barotrauma, frequently affects the lungs[26] and may be a contributing factor to the demonstrated increase. Finally, VAP is known to be inconsistently measured and often diagnosed subjectively.[27] The perceived system increase in VAP early in 2011 may have influenced physicians to be more attentive to signs and symptoms or to diagnose VAP earlier in the continuum of care. Of note, in 2011, seven cases of VAP (six of which were in the second half of the year) were diagnosed in Germany at the Level IV military treatment facilities. By contrast, in 2010, no VAP diagnoses were made at that level of care. This seems to suggest increased physician awareness to a systemic complication trend.

There are limitations to the JTS monitoring of VAP. The primary limitation is that US Navy medical centers do not participate in the JTTR. National Naval Medical Center (NNMC) in Bethesda, Maryland, and, to a lesser degree, Naval Medical Center San Diego received many trauma patients from theater for their definitive care in the United States. The location of tertiary care has varied during the conflicts, sometimes determined by injury type but more often decided by the patient's service affiliation. For example, Marine Corps and Navy patients were likely to go to Navy medical centers and Army and Air Force patients to Army medical centers. Approximately 30% of this sample's patients were lost for tertiary facility (Level V) data collection in the JTTR. Another limitation is that this evaluation was limited to trauma patients who had ventilation initiated in the combat theater. Trauma patients with ventilation initiated after theater evacuation are relevant to the trauma system and should be considered for inclusion in future reviews. In addition, all patients ventilated for disease or other nontrauma diagnoses would need to be included for any truly global military health system rate of VAP.

Acute compartment syndrome is a concern for any patient who has experienced extremity trauma. Left untreated, it can result in limb loss or even death. Trauma-related compartment syndrome is most often associated with closed long-bone fractures but may also occur with open fractures, burns, and penetrating extremity injury.[28] The primary treatment for extremity compartment syndrome is expeditious fasciotomy to relieve muscle compartment pressure.[29]

Extremity compartment syndrome is of particular concern in combat trauma. Increased survivability in the wars in Iraq and Afghanistan has increased the number of casualties presenting with complex orthopedic injuries.[30–32] Fasciotomy is intended to maximize functional outcome as well reduce the risk of complications such as amputation. Limb ischemia is the most significant predictor of amputation in military injuries. Fasciotomy, in addition to other limb salvage procedures, has an important role in limb reperfusion.[33] Ritenour et al.[34] found that combat casualties with delayed fasciotomy had twice the rate of major amputation and three times the rate of mortality. The same study showed that fasciotomies that required later revision had a fourfold increase in mortality. Surgeons can be reluctant to perform prophylactic fasciotomies. In addition to performance of a possibly unnecessary surgical procedure, battlefield fasciotomies have been associated with infectious complications.[35] Kragh et al.[36] observed an increased willingness, after controlling for injury severity, to perform fasciotomies from 2003 to 2006. This was attributed to increased clinician training as well as trauma system communication and feedback related to patient outcomes to providers in theater.

US military trauma surgeons noted that the rate of compartment syndrome had reached alarming levels even before the peak in 2005. Formation of the JTTS in 2004 assisted in a coordinated response to the emerging complication trend. Accurate, in-theater data collection enabled evidence-based training for deploying clinicians as well as subsequent research to validate the system intervention and establish best practices. From 2003 to 2007, between 40% and 75% of fasciotomies performed were in response to compartment syndrome. There was a very marked change during 2008 to 2011 when 10% to 25% of fasciotomies were in response to compartment syndrome, indicating that a higher proportion was done prophylactically or empirically in compliance with the CPG.

There are some basic limitations to this system-level evaluation. All extremity injuries were included in the evaluation, including minor and moderate injury (AIS score of 1 or 2). Although including less severe injuries may have increased the sample denominator, some cases of compartment syndrome did result from less severe injuries. The choice was made to capture as many cases as possible across the evaluation period. In addition, at this time, it cannot be determined whether the fasciotomies were performed prophylactically based on a risk factor assessment that would indicate a higher likelihood of developing compartment syndrome, given the patient's profile

or upon early signs and symptoms of compartment syndrome. Although the difference may not affect final patient outcomes, it is an important element when assessing physician adherence to clinical guidelines.

Toward the end of 2010, multiple military medical facilities expressed concern that there was an increasing incidence of DVT and PE in the postamputation population within the JTS. Since some of those facilities expressing concern did not, at that time, enter their trauma data into the JTTR, the full extent of any perceived increase could not be measured at the system level. Regardless, 2010 had the highest number of amputations of any year of the wars, and VTE is a complication of ongoing concern in major traumas, so a focused system PI project was initiated to identify any risk factors that might be contributing to an increase. The initial review was concerned with all patients who had an amputation in Afghanistan in 2010. The findings of that first PI review suggested possible associations between MT and DVT as well as hypothermia and PE. In addition, there was a possible protective effect from prehospital tourniquet use to DVT. These initial PI results generated additional interest, which led to this more formal follow-up PI review with a larger sample size, extensive chart review, and significantly more variables for analysis.

VTE is a frequent and serious complication of trauma. Several risk factors common in combat trauma have been associated with VTE, including head or spinal cord injury, transfusion, fractures of the lower extremity and pelvis, and a high ISS.[37] Knudson et al.[38] found that chest injury also increases the risk for PE. A study of combat casualties completed by Gillern et al.[39] found a higher incidence of PE for patients with trauma-related amputation when compared with patients with extremity long-bone fractures without amputation. Additional findings showed that bilateral amputations, multiple long-bone fractures, and pelvic fractures were independent risk factors for PE. Prolonged immobility after injury can contribute to VTE in trauma patients. Lengthy intercontinental air evacuations from the theaters of war to definitive care in the United States may place combat trauma patients at higher risk for VTE. However, a case-control study with military burn patients completed by Chung et al.[40] found that prolonged global evacuation was not associated with VTE.

The significant findings related to VTE were not unexpected with the possible exception of use of central lines with DVT. Perhaps, more interesting is that variables commonly associated with VTE prevention, in-theater anticoagulation, and sequential compression devices were not significantly associated with a reduction of cases. In addition, the system policy change during the period of review to increase epidural use for pain control during evacuation from theater was not associated with a significant increase in VTE. Interestingly, the packed red blood cell MT and platelet use were associated with DVT, but use of whole blood was not. Future analysis should focus on resuscitation factors and their interactions with adjunct therapies such as TXA or factor VIIa. The findings of this PI review will inform the JTS CPGs to identify who may be at greater risk for VTE and when to use preventive treatments such as inferior vena cava filters. All trauma patients are now routinely screened for DVT upon admission to US Level IV care in Germany to assist in early identification of patients with VTE.

There are limitations to this focused system PI review of amputation patients. The findings are only generalizable to patients who underwent amputation. Patients who underwent amputation are often polytrauma patients, and as such, findings may be attributable to other patient care factors. The conflict in Afghanistan is a multinational operation, and differences between patient outcomes may be related to the differential patient care practices of coalition medical forces. Although an extensive system review was conducted by the JTS, it is likely some events of patient with VTE were missed during the review process, particularly at US Navy medical centers since they did not participate in the JTTR during the time of the PI review. Furthermore, 30 patients (10.1%) did receive inferior vena cava filters during the course of their care, possibly preventing pulmonary emboli that may have occurred otherwise.

CONCLUSION

The JTS enables evidence-based practice across the continuum of military trauma care. Concurrent data collection and PI activities, at the local and system levels, facilitate timely clinical intervention on identified trauma complications and the subsequent measurement of the effectiveness of those interventions. The trauma system operates in a continuous cycle of assessment, implementation, and evaluation that enables responsive adaptations to emerging or reemerging trauma complications in its patient population.

AUTHORSHIP

All authors contributed to the study design. K.P., A.A., and G.F. performed the data collection. K.P., A.A., G.F., and B.J.E. performed the data analysis. K.P., A.A., D.S., G.C., J.B., G.F., L.H.B., and B.J.E. prepared the article.

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DISCLOSURE

The authors declare no conflicts of interest.

REFERENCES

1. Eastridge B, Jenkins D, Flaherty S, Schiller H, Holcomb J. Trauma system development in a theater of war: experiences from Operation Iraqi Freedom and Operation Enduring Freedom. *J Trauma*. 2006;61:1366 1373.
2. Bridges E, et al. Advancing critical care: Joint Combat Casualty Research Team and Joint Theater Trauma System. *AACN Adv Crit Care*. 2010;21: 260 276.
3. Cordts P, Brosch L, Holcomb J. Now and then: combat casualty care policies for Operation Iraqi Freedom and Operation Enduring Freedom compared with those of Vietnam. *J Trauma*. 2008;64:S14 S20.
4. Blackbourne L. The next generation of combat casualty care. *J Trauma*. 2009;66:S27 S28.
5. Eastridge B, Wade C, Spott M, et al. Utilizing a trauma systems Approach to benchmark and improve combat casualty care. *J Trauma*. 2010;69:S5 S9.
6. Centers for Disease Control and Prevention. Guidelines for preventing health-care associated pneumonia, 2003: recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee. *MMWR Morb Mortal Wkly Rep*. 2004; 53:No. RR-3.

7. Dudeck M, Horan T, et al. National Healthcare Safety Network (NHSN) Report, data summary for 2010, device-associated module. *Am J Infect Control*. 2011;39:798 816.
8. Augustyn B. Ventilator-associated pneumonia: risk factors and prevention. *Crit Care Nurse*. 2007;27:32 39.
9. Morris A, Conway MB, Hay A, et al. Reducing ventilator-associated pneumonia in intensive care: impact of implementing a care bundle. *Crit Care Med*. 2011;39:2218 2224.
10. Grap M. Not-so-trivial pursuit: mechanical ventilation risk reduction. *Am J Crit Care*. 2009;18:299 309.
11. Cavalcanti M, Ferrer M, et al. Risk and prognostic factors of ventilator-associated pneumonia in trauma patients. *Crit Care Med*. 2006;34: 1067 1072.
12. Conger N, Landrum M, Jenkins D, Martin R, Dunne J, Hirsch E. Prevention and management of infections associated with combat-related thoracic and abdominal cavity injuries. *J Trauma*. 2008;64:S257 S264.
13. Murray C, Wilkins K, Molter N, et al. Infections complicating the care of combat casualties during Operations Iraqi Freedom and Enduring Freedom. *J Trauma*. 2011;71:S62 S73.
14. Smith K. Critical care nursing in an austere environment. *Crit Care Med*. 2008;36:S297 S303.
15. Shah K, Pirie S, et al. Utilization profile of the trauma intensive care unit at the Role 3 Multinational Medical Unit at Kandahar Airfield between May 1 and Oct. 15, 2009. *Can J Surg*. 2011;54(Suppl 6):S130 S134.
16. Hospenthal D, Crouch H. Infection control challenges in deployed US military treatment facilities. *J Trauma*. 2009;66:S120 S128.
17. Johnson E, Marconi V, Murray C. Hospital-acquired device-associated infections at a deployed military hospital in Iraq. *J Trauma*. 2009;66: S157 S163.
18. Koenig S, Truwit J. Ventilator-associated pneumonia: diagnosis, treatment, and prevention. *Clin Microbiol Rev.* 2006;19:637.
19. Fang R, Pruitt V, et al. Critical care at Landstuhl Regional Medical Center. *Crit Care Med*. 2008;36:S383 S387.
20. Colombo C, Mount C, Popa C. Critical care medicine at Walter Reed Army Medical Center in support of the global war on terrorism. *Crit Care Med*. 2008;36:S38 S394.
21. Venticinque S, Grathwohl K. Critical care in the austere environment: providing exceptional care in unusual places. *Crit Care Med*. 2008;36: S284 S292.
22. Murray C. Infectious disease complications of combat-related injuries. *Crit Care Med*. 2008;36:S358 S364.
23. Landrum M, Murray C. Ventilator associated pneumonia in a military deployed setting: the Impact of an Aggressive Infection Control Program. *J Trauma*. 2008;64:S123 S128.
24. Grathwohl K, Venticinque S. Organizational characteristics of the austere intensive care unit: the evolution of military trauma and critical care medicine; applications for civilian medical care systems. *Crit Care Med*. 2008;36:S275 S283.
25. Lettieri C, Shah A, Greenburg D. An intensivist-directed intensive care unit improves clinical outcomes in a combat zone. *Crit Care Med*. 2009;37:1256 1260.
26. Scott S, et al. Mechanism-of-injury approach to evaluating patients with blast-related polytrauma. *J Am Osteopath Assoc*. 2006;106:265 270.
27. Halpern N, Hale K, Sepkowitz K, Pastores S. A world without ventilator-associated pneumonia: time to abandon surveillance and deconstruct the bundle. *Crit Care Med*. 2012;40:267 270.
28. Balogh Z, Butcher N. Compartment syndromes from head to toe. *Crit Care Med*. 2010;38:S445 S451.
29. Salcido R, Lepre S. Compartment syndrome: wound care considerations. *Adv Skin Wound Care*. 2007;20:566 567.
30. Belmont P, Thomas D, Goodman G, et al. Combat musculoskeletal wounds in a US Army Brigade Combat Team during Operation Iraqi Freedom. *J Trauma*. 2011;71:E1 E7.
31. Taylor C, Jeffery S. Management of military wounds in the modern era. *Wounds UK*. 2009;5:50 58.
32. Brown K, Guthrie H, Ramasamy A, Kendrew J, Clasper J. Modern military surgery lessons from Iraq and Afghanistan. *J Bone Joint Surg Br*. 2012;94:536 543.
33. Percival T, Rasmussen T. Reperfusion strategies in the management of extremity vascular injury with ischaemia. *Br J Surg*. 2012;99:66 74.
34. Ritenour A, Dorlac W, Fang R, et al. Complications after fasciotomy revision and delayed compartment release in combat patients. *J Trauma*. 2008;64:S153 S162.
35. Brown K, Murray C, Clasper J. Infectious complications of combat-related mangled extremity injuries in the British military. *J Trauma*. 2010; 69:S109 S115.
36. Kragh J, et al. Fasciotomy rates in Operations Enduring Freedom and Iraqi Freedom: association with injury severity and tourniquet use. *J Orthop Trauma*. 2011;25:134 139.
37. Koepplinger M, Jaeblon T. Venous thromboembolism diagnosis and prophylaxis in the trauma population. *Curr Orthop Pract*. 2010;21:301 305.
38. Knudson M, Gomez D, Haas B, Cohen M, Nathens A. Three thousand seven hundred Thirty-eight posttraumatic pulmonary emboli: a new look at an old disease. *Ann Surg*. 2011;254:625 632.
39. Gillern S, Sheppard F, Evans K, et al. Incidence of pulmonary embolus in combat casualties with extremity amputations and fractures. *J Trauma*. 2011;71:607 613.
40. Chung K, Blackbourne L, Renz E, et al. Global evacuation of burn patients does not increase the incidence of venous thromboembolic complications. *J Trauma*. 2008;65:19 24.

